IS THERE ANY DIFFERENCE BETWEEN AN OBJECTIVE AND SUBJECTIVE EVALUATION OF READING DIFFICULTY DUE TO WHOLE BODY VIBRATION (WBV)?

Duarte, M.L.M., mlduarte@dedalus.lcc.ufmg.br
Arenales, G.G.R., guiroca@gmail.com
$GRAVI_{HB}$: Group of Acoustics and Vibration in Human Beings, DEMEC/UFMG: Mechanical Engineering Departament of the Federal University of Minas Gerais, Av. Antônio Carlos, 6627 – Pampulha, Belo Horizonte/MG, Brazil, 31270-901

Faria, L.N., lauraniquini@agenciadelfos.com.br
Eyes Hospital of Minas Gerais (Hospital de Olhos de MG), Dr. Ricardo Guimarães Clinic, Rua da Paisagem, 270 – Belo Horizonte/MG, Brazil

Abstract: *It is very common in human beings laboratory studies to perform an evaluation of the results considering the subjective response of the volunteer. Although that methodology should never be forgotten, if there is the possibility to estimate the results in a more objective way, that should also be considered. However, there is no guarantee that the results will be the same and this should be taken into consideration when interpreting the results. If this is the case, an investigation on the quality of both results should be undertaken to explain why that happened and to help decide which result will be trustful. The main objective of this paper is to compare if the subjective and objective evaluation of the influence of whole body vibration (WBV) during reading activities are the same. Whole body vibration is very common on the everyday of people, either during leisure activities or work. However, its presence should not decrease the quality of the task being performed, as reading a text or a command panel, for example. With that in mind, a laboratory study was devised to evaluate the influence of the WBV during reading when some parameters as reading position and amplitude are changed. An eye tracker device was used to monitor, in an objective way, the volunteers´ quality of reading. At the end of each test, the volunteer accessed his/her degree of reading difficulty using a subjective scale. So, such results are compared in order to verify if the subjective evaluation should be disregarded in favor of the objective assessment. Suggestions about that are given on the conclusions.*

Keywords: *whole- body vibration (WBV), Reading, Eye Tracker*

1. INTRODUCTION

There are several situations when it is necessary to perform a certain task in the presence of whole-body vibration (WBV). Whole body vibration is considered to be the one that enters the body as a whole. It may be produced by machinery, building vibration, vehicles and earth movement, among others. When submitted to that, it may be necessary to read a text (either for work or leisure), to write a note, or even to drink a liquid, for example.

This paper focuses the influence of the WBV when performing a reading task. In that sense, both the object and the subject may be vibrating, only the object may be vibrating or only the subject may be vibrating. The research described here has the aim to investigate the situation when both the subject and the object are vibrating. Different text positions and amplitudes are considered. It tried to simulate passengers reading a text or a driver reading a command panel inside vehicles. As mentioned in (Griffin, 1996), there is no simple universal answer to what amplitude of vibration is required to cause decrements in vision or how this amplitude depends on the vibration frequency. Several factors interfere in such evaluation. In that reference, it is possible to find an explanation about the vision process and therefore, the parameters involved. When thinking about vehicle vibration and reading, the amplitude and frequency of vibration, as well as the text position, are important points to be observed. Regarding vibration, what varies from one type of vehicle to the other is the main frequency, vibration intermittence and amplitude a subject is submitted when in WBV.

Whole-body vibration evaluations are generally performed using either the weighted RMS acceleration (m/s^2) or the Vibration Dose Value (VDV) ($m/s^{1.75}$) (Griffin, 1996), (ISO2631-1, 1997). The accelerometer has to be placed as close as possible to the first contact point between the vibration source and the subject. The energy transmitted to the subject is linked to both the exposure time and amplitude (ISO2631-1, 1997). All vibration measurements should be made in reference to a daily exposure of 8h a day and the values set by the European Parliament (Directive 2002/44/EC, 2002) should be used for that. On the Internet is possible to find calculators (HSE, 2006) to perform such calculation according to the (ISO2631-1, 1997) standard, following the values set by the (Directive 2002/44/EC, 2002). The recommendations of the ISO13090-1 standard (ISO13090-1, 1998) should also be observed in order to guarantee the safety of the volunteers during the tests performed.

The ISPESL (Istittuto Superiore per la Prevenzione e la Sicurezza del Lavoro) in Italy has also on the internet a database containing a list of different types of vehicles, from buses, to trucks, trains, etc. where it is possible to find the main amplitude content of each vehicle according to the ISO2631-1 (ISO2631-1, 1997) and the European Directive

(Directive 2002/44/EC, 2002). Such values may be either declared by the manufactures or measured (ISPESL, 2008). However, no mention is made about the frequency content, as a more sophisticated instrumentation is required to get such characteristic. However, there, it is possible to see that the maximum amplitude values vary a lot, depending on the type of vehicle, manufacturer, etc. Some range from below the EAV (Exposure Action Value) of 0.5 m/s^2, others to above the ELV (Exposure Limit Value) of 1.15 m/s^2 set by the (Directive 2002/44/EC, 2002) for an 8h exposure.

A comprehensive list of the main vibration characteristics for same typical vehicles is presented in (Balbinot, 2001) and (de Oliveira, 2007). Off-road vehicles characteristics are presented in (Diaz, et al., 2003) and (Mabbot, et al., 2001). From such references, it was possible to see that the main frequency of most of the vehicles is around 4 to 8 Hz. Besides, in this range, the weighting curves of the ISO2631-1 (ISO2631-1, 1997) are close to unity, decreasing therefore, its influence on the results obtained, as this fact was questioned in (Morioka, 2008). Moreover, (Liang, 2006) showed that the highest seat-to-head (STH) transmissibility occurs around 5 Hz, minimizing the level of excitation necessary for the subject to feel the vibration.

Therefore, in this work the main parameters found in automotive vehicles were used, since that is the main application of the current research. Some previous studies undertaken by $GRAVI_{HB/UFMG}$ (Group of Acoustics and Vibration on Human Beings of UFMG) researchers have investigated the influence that the amplitude of vibration (Duarte, et al., 2008a) and text position (Duarte, et al., 2008b) have on the difficulty of reading a text. However, on such studies, only a subjective evaluation of the reading difficulty was obtained. Therefore, the tests were repeated using an eye tracker device to monitor, in an objective way, the reading difficulty by monitoring the saccadic movement of the eyes. For that, several different parameters can be used (Taylor Online Inc, 2008b), some of which will be investigated in this work. The saccadic movement is a measure of the degree of reading difficulty (Wikipedia, 2009). It may change in the presence of external agents, such as the WBV, and becomes an objective indicator of such difficulty.

This paper is organized as follows: first, the setup, as well as the instrumentation used during the tests, is presented. That is followed by the methodology of the tests, including there the volunteers´ selection, the tests description and a description about the objective and subjective parameters chosen. Then, the results obtained are presented and interpreted. Finally, the conclusions are drawn.

2. SETUP AND INSTRUMENTATION USED

Figure 1 shows a schematic view of the setup used for the tests presented here with a photo of such configuration shown in Figure 2.

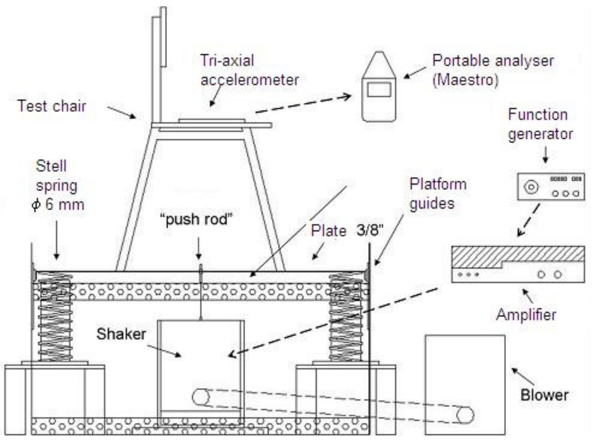

Figure 1. Schematic drawing of the WBV setup and instrumentation.


Figure 2. Photo of the setup used for WBV Reading Tests

The vibrating platform consisted of a steel plate (700 x 1000 x 3 mm and folded edges), supported by four 1020 steel compression springs (76 mm external diameter, 350 mm height, 6 mm wire diameter and 9 coils). PVC tubes positioned outside a steel tube welded into a flat metal basis were used to guide the springs. That assembly was used to ensure the vertical motion of the spring, reducing fluctuations in the x- and y- axis. Therefore, the main excitation was in the z-axis, as this is the direction of greatest interest for this work. The platform was also guided by a metal structure, with polypropylene plates fixed at its internal corners, lubricated with grease to decrease the friction between these plates and the ones made of the same material and fixed at the corners of the platform.

A Dynamics Solution shaker, VTS150 model, was installed under the plate. A steel push rod (2.0 mm diameter, 100 mm length, bolted at each end to a 60 mm and 30 mm length 4.0 mm diameter screws) was used to transmit the sinusoidal signal used during the tests from the shaker to the platform. The screws at the end of the push rod were used to control the height of the push rod according to the weight of each volunteer.

The sinusoidal signal was generated by a Topward Function Generator 8102 and amplified by a Crown Amplifier CE2000. A tri-axial accelerometer APTechnologies AP5213 was placed at the chair seat and connected to a four channels analyzer, model Maestro® from 01dB. The measurements were performed using the built in weighting functions of the ISO 2631-1 standard for whole body vibration (ISO2631-1, 1997). Therefore, it was the weighted acceleration measured by the accelerometer and provided by the analyzer that was used to adjust the amplitude of the signal sent by the generator up to the desired level for each test performed.

The volunteers were sat during the whole length to the test on a chair having wooden seat/backrest and metallic feet positioned on the top of this assembly (see Figure 3). In front of the chair, at the platform width centre, a metal rod was fixed by screws (1 mm thick, 20 mm square section and 1 m height), having at its upper end a wooden support for reading (10 mm thick, 355 mm wide and 410 mm long) with a 45^{o} slope. This assembly, rod/reading support, will be called from now on pedestal. Figure 3 shows details of this pedestal and chair used during the tests.

Figure 3. Details of the pedestal and chair used during the reading WBV tests

During all tests presented here, an Eye-Movement Recording/Assessment System called Visagraph III from Taylor Online Inc. was used to monitor the reading difficulty in an objective way, using a Taylor National Norm (Taylor Online Inc, 2008a), as shown in Figure 4 (Taylor Online Inc, 2008b). The time taken to perform the reading task considered in this work was monitored using a regular chronometer.

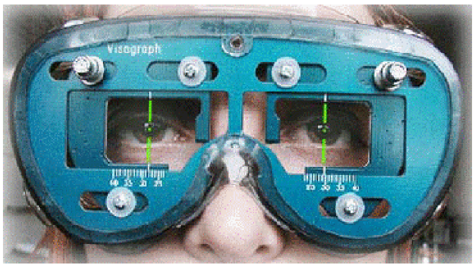

Figure 4. The visagraph III device used to monitor the eye movement

3. METHODOLOGY

3.1.Volunteers Selection

Due to, but not only, the easiness of recruitment, all volunteers who attended the tests were students from the Federal University of Minas Gerais (UFMG). At first they filled in a form about their health history, therefore, their actual condition to take part in vibration tests. If they had any impediment, they would be excluded from the tests already at this first stage. On the contrary, they were given an explanation on how the tests would be conducted and signed a free and informed consent for taking part in the experiments. The research was approved by Research Ethics Committee of the UFMG. Such procedure was required by them, although it is also recommended by (Griffin, 1996) and by the (ISO13090-1, 1998) standard. Since the main objective of the tests was to verify the influence of the WBV during reading, if the volunteer had any serious eyesight problem, he/she would also be excluded from the tests. Common sight problems which could be correct using eye glasses or contact lenses were not an impediment to take part in the experiments, as long as the volunteer used such correction during the tests. Therefore, to verify that and to confirm that the correction was right, all volunteers were submitted to normal ophthalmological tests prior to the vibration tests. Such information was put on the volunteers test sheet for further records. However, during the tests some volunteers that used eyesight corrections had problems with the eye tracker device and their data could not be recorded. Therefore, at the end, they could not be included in the analysis for that reason.

A total of 16 subjects took part in the present research. Each subject performed all the tests proposed, being a total of 6 different situations, as it will be described in the following section 3.2. The number of volunteers was established to allow a statistical evaluation of the results if necessary. Usually, researches involving evaluations of the vibration effects in human use between 8 to 30 subjects. The work presented here, therefore, is within that range. However, due to the above mentioned problem with the eye tracker device and some other problems with it, at the end, not all data could be recorded and for some experiments, the number of subjects is smaller than the one mentioned.

3.2.Tests Description

In order to verify the influence of WBV during reading, the volunteers sat still in a wooden chair having a backrest but no cushion throughout all six tests, as mentioned in the previous section. Table 1 presents the main vibration and position characteristics of each test.

Table 1. Summary of the tests reported here

Test number	Frequency (Hz)	Weighted RMS acceleration (m/s^2)	Text Position
T1	Static	No vibration	Hand held clipboard
T2	Static	No vibration	Pedestal
T3	5 Hz	0.8	Hand held clipboard
T4	5 Hz	0.8	Pedestal
T5	5 Hz	1.4	Hand held clipboard
T6	5 Hz	1.4	Pedestal

The saccadic eyes movement (Wikipedia, 2009) was monitored using goggles placed by the examiner over the volunteer´s eyes, adjusted in relation to the volunteer´s pupil, as already shown in Figure 4 (Taylor Online Inc, 2008b). The volunteer then had to read a short text selected among the options available inside a test booklet and at the end of the reading had to answer 10 questions to determine his/her comprehension of the text. However, these answers were used in the present research only to stop the software acquisition, not really to evaluate the reading comprehension. Simulation of the eye-movements over text, multiple reports and data presentation were then auto-generated by the software provided with the eye tracker device (Taylor Online Inc, 2008a). It is important to mention here that the texts used during the tests were translated from English to Portuguese although, for the software, it is assumed the English version. Therefore, for some words, the number of characters between the languages may be different, fact that was not taken into consideration by the software. Moreover, in the translation, the number of words per line was kept the same between the languages and the text alignment was justified. Therefore, it could have happen that at some lines the spacing between the words was altered, affecting the reading quality. That fact may also be important in order to analyze the data obtained.

The text used was changed from test to test and were chosen to be in a level compatible to the volunteer´s age and comprehension. Such procedure was adopted in order to avoid previous knowledge of the contents, what could mask both the real time taken and the degree of difficulty to accomplish such task. The time taken to read the text was measured using a regular chronometer. The same text was used for all volunteers in the same test situation, although, for some volunteers, due to a problem with the acquisition software, a different text was tried. However, such data was discarded at the end of the analysis, since it did not correspond to the same test characteristics, although it was very similar to T6. It was used only to test the equipment. Table 2 shows the main characteristics of the texts used, apart from this alternative one. As it can be seen there, the selected texts in the booklet (Text #) had levels considered similar (that is, 6 or 7) and similar characteristics. Only test T3 that had total number of characters smaller than the others. Therefore, some other characteristics related to that were also smaller.

Table 2. Summary of the texts characteristics

Test Number	Text #	Level	Mean Words/Line	Mean Character/Line	Total Words	Total Characters	Mean Characters/Words
T1	78	7	9.83	48.0	118	576	4.881
T2	77	7	10	46.2	120	554	4.617
T3	65	6	9.67	38.0	116	456	3.931
T4	79	7	9.58	44.9	115	539	4.687
T5	74	6	9.54	41.9	124	544	4.387
T6	66	6	9.92	42.2	119	506	4.252

3.3.Objective Parameters Used

As mentioned in the previous section, the software included with the Visagraph III eye tracker device records several different parameters to monitor the eye-movements over text. They can be used to evaluate the degree of difficulty of reading the text and some of them will be used here as analysis parameters. The parameters chosen are: 1) fixation, 2) average span recognition and 3) time. Fixation means how many times the volunteers fixed their eyes to read the text and so, more fixations translate a poorer reading. Therefore, a high number of fixations mean a more difficult reading. The average span recognition is a variable that tells the capability of the reader to span the words in the text. Therefore, it measures the visual field the subject can read. The goal of this variable is the bigger the span, the better is the reading. Time is how long the subject spent to read. Regression could also have being used as an objective parameter; however, its behavior was similar to the fixation parameter and, therefore, it will not be presented. Regression means the eye movement to return to the previous word, that is, the bigger the number of regressions, the worse (more difficult) is the reading. Therefore, the better the reading, the lower number of regressions is expected. The results presented in the following section will be analyzed with these comments in mind.

3.4.Subjective Parameters Used

The first test (without WBV) was used as the reference one for post comparison and there was no subjective evaluation regarding it. For all the other tests, just after finishing reading the text, the volunteer had to qualify the easiness of reading using pre-established scales (both numeric, as well as, conceptual). However, only the numeric scale will be presented here. It varied from 0 to 10 (from extremely easy to impossible to read) according to the volunteers´ judgment, whereas the conceptual had only 5 levels. Therefore it covered a wider range of values.

4. RESULTS

The results presented in this section are going to be compared assuming the same text position in each figure to easy the evaluation of the WBV amplitude influence. Therefore, tests T1, T3 and T5, corresponding to the text hold by the volunteer are presented on the left side of the following figures, whereas, tests T2, T4 and T6, corresponding to the text position at the pedestal are presented on the right side of the same figures.

During the tests, four (4) volunteers had problems with the eye tracker device and a different text was used just to continue with the other experiments. Therefore, their data are not included in the analysis for that particular test, since it did not correspond to the same test, as already mentioned. These tests are T1 for volunteers V8 and V12; T3 for volunteer V2 and T5 for volunteer V1. As for some other tests, although the same text was used, the eye tracker device could not record the data. Such fact happened more frequently with the text at the pedestal, as it will be seem in the following figures.

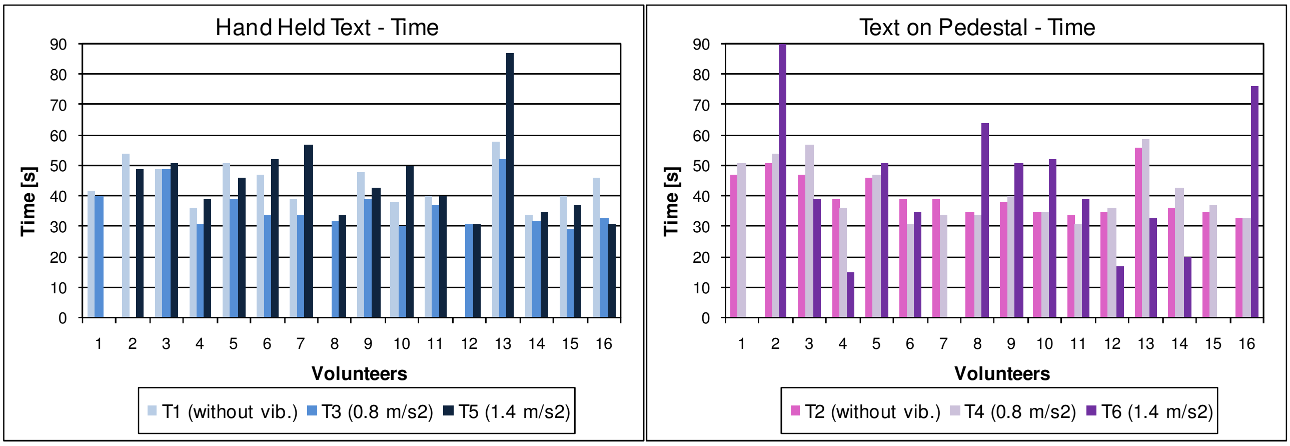

Figure 5. Time taken to perform the reading task

Analyzing the time taken to read the texts (Figure 5) – considered an objective evaluation for the performance of reading – it can be seen that, when the text is hand held, an interesting fact happened. In general, the subjects spent less time to read the text in the presence of the low vibration amplitude (T3, 0.8 m/s^2) than without vibration (T1). Such behavior was not the expected one, since the presence of WBV was expected to interfere in the reading. However, that fact may be explained by two reasons. The first is related to the level of T1 (higher than for T3 and T5, although similar). The second is related to the other characteristics of T3. Although the mean words/line is not much different from the other tests presented, all the other characteristics related to the number of characters are smaller for T3 than for T1 and T5 (see Table 2). So, that may have influenced the reading quality. Comparing the reading time in the presence of vibration, but with different amplitudes (T3 with T5), as the vibration amplitude increased, the time to perform the reading was also increased for the majority of the subjects, apart from volunteers V12 and V16, which were not much different in any case. Analyzing the tests with the text at the pedestal (T2, T4 and T6), right side of Figure 5, the time presented for T6 cannot be considered in some cases, as some subjects considered the reading so difficult that they gave up reading before finishing the text. An association with that can be made when analyzing the right side of Figure 6. That explains why comparing T4 with T6 the time is smaller for some subjects. Therefore, the comparison can be trusted only between T2 and T4 and analyzing that, it can be seen that there is no strong tendency here, although it may be considered that in the presence of vibration the reading took longer. Nevertheless, it is possible to see for some volunteers, that the opposite happened or the time was approximately the same, again, in contradiction of what was expected (that is, WBV should influence reading). Comparing the time to read the text hand held with the ones at the pedestal, they followed more or less the same behavior for each volunteer. The comments made for T1 compared with the other tests are still valid, making its time to be higher than for the other tests with low vibration amplitude regardless of the text position. However, do not considering the time for T1 for the reasons mentioned, for the same test condition, it can be observed that the reading on the pedestal was in general more time consuming.

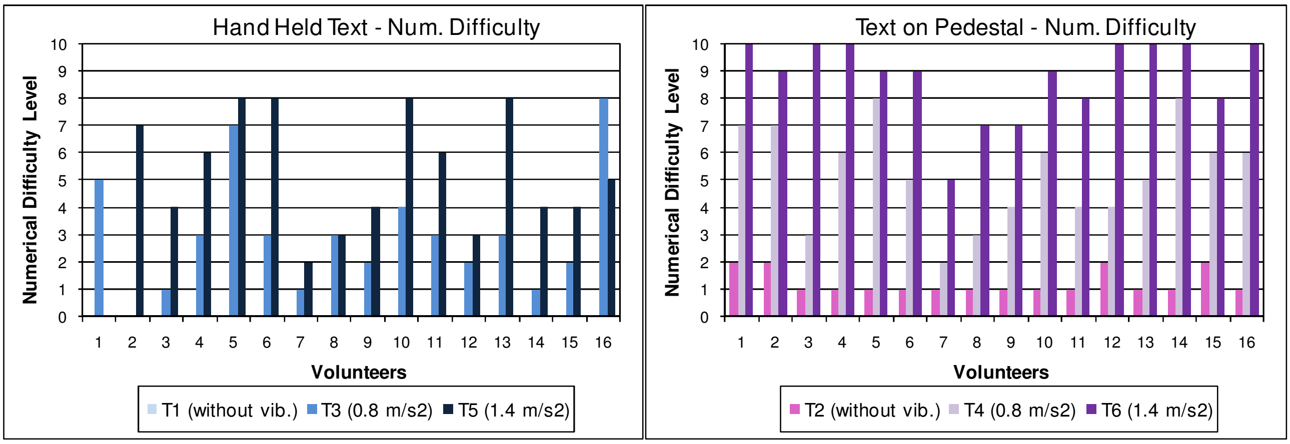

Figure 6. Numerical Difficulty evaluation by the volunteers

Figure 6 shows the numerical difficulty evaluation by each subject, according to the range presented in section 3.3. When the results are compared considering the same text position, it can be seen again that the higher the amplitude, the more difficult the reading is, as evaluated subjectively by the subject. It is not possible to compare the reading difficulty without vibration (T1) as for the subjective evaluation that test was assumed to be the reference one and it was assumed to be 0 (zero), that is, extremely easy. Such value was based on some other subjective experiments undertaken by the GRAVI_{HB} researchers which concluded that the text hold by the volunteer was the least difficulty to read (Duarte, et al., 2008b). However, looking at all the other parameters presented in the following figures, the subjective evaluation should also have been considered for the test without vibration. Therefore, that is a suggestion for future work continuation. When comparing the difficulty assessment with the text hand held or at the pedestal (left and right side of Figure 6, respectively), the latter was more difficult, although such behavior was not so clear considering the time taken to read as presented in Figure 5. The reason may be the influence of the use of the eye tracker device disturbing the volunteer´s reading.

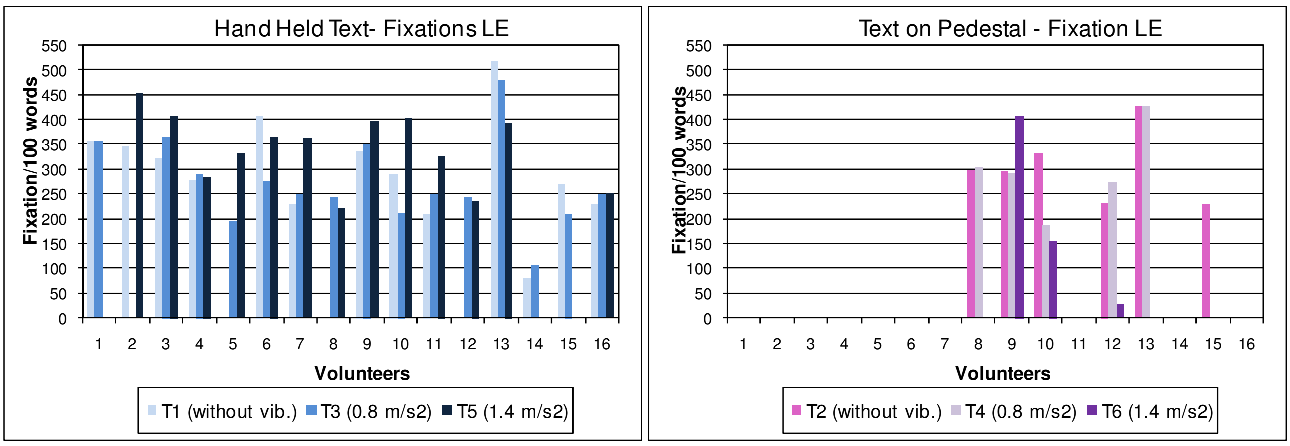

Figure 7. Fixations left eye

Figure 7 shows the amount of left eye´s fixations for groups of 100 words. Right and left eye results were a lot close, therefore, only the left eye values are presented for an easiness of interpretation. As mentioned in session 3.3, for a good reading, the number of fixations should be small. For the text hand held it was possible to record almost all data, whereas, at the pedestal, due to a problem with the eye tracker device, mainly the first subjects did not have their data recorded. For the former, some of the data are not presented also due to the problem mentioned at the beginning of this section about the use of a different text. Analyzing both sides of this figure is not possible to get a definite conclusion about the influence of the WBV on reading, since the behavior varies a lot. Some volunteers had a big number of fixations when the vibration amplitude was increased (T3 with T5), indicating a more difficult reading, as expected. However, some other volunteers had a small number of fixations in the same situation. Nevertheless, for this objective evaluation parameter, there is a slightly higher increase on the number of fixation with WBV increase than the opposite. Such fact may suggest that the higher the WBV amplitude, the more difficulty is the reading. Since the texts used for reading were in Portuguese and the software assumed the English version, such fact may also have influenced the results obtained.

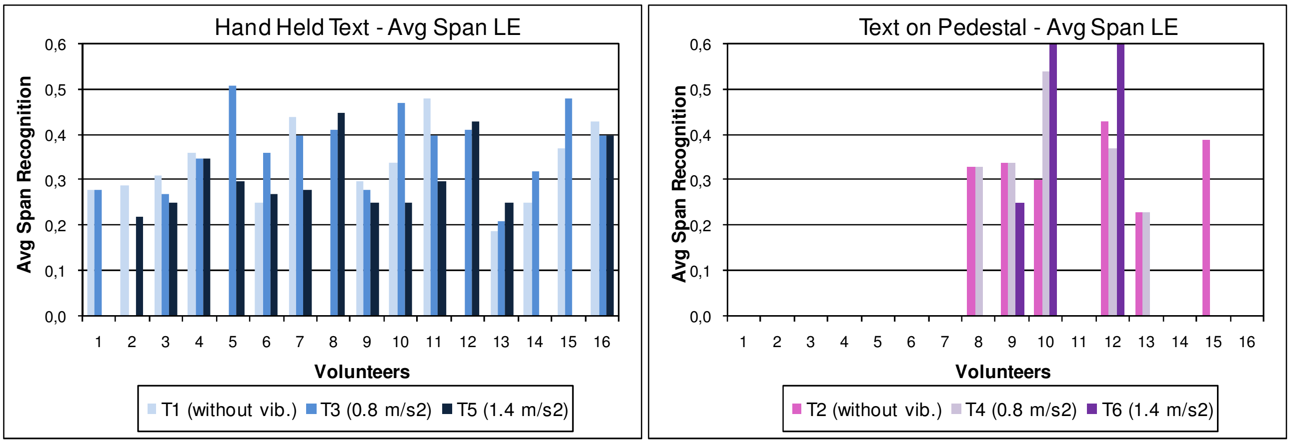

Figure 8. Average Span of Recognition for left eye

The behavior of the objective parameter average span of recognition presented in Figure 8 was exactly the same as the fixation parameter presented in Figure 7, since its value increase where the fixation is small and decrease where the fixation value is big. Therefore, the same conclusions are drawn.

Comparing the subjective and objective evaluations, it can be seen a clear pattern on the subjective evaluation that was not clear with the objective evaluation measured by the eye tracker device. Only the objective parameter time that showed a pattern. However, there are several doubts about the way the objective parameters were collect, as mentioned before and it will be presented in the following section again.

5. CONCLUSIONS

This work had the aim to investigate if subjective evaluations should be disregarded in favor of more objective evaluations. For the data presented here, although there is a very clear pattern when using a subjective evaluation that the higher the amplitude, the more difficult is the reading and if the text is hand held is easier to read than with it at a pedestal, such behavior was not evident on the objective evaluation. However, the texts used during the experiments were in Portuguese, whereas the software used assumed the English version. Moreover, the spacing between the words in each text was different since the text in Portuguese assumed the same number of words/line as in the English version and the alignment was justified. Therefore, that may have influenced the results as well. Therefore, before continuing with such investigation, it is necessary to correct the software used first. Currently, the LABBIO Group of Federal University of Minas Gerais is developing a similar eye tracker device with its own software, where such problems would be corrected.

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